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REPORT

Digital methods for the timing correction of television signals

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OF TELEVISION SIGNALS
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Summary

Alternatives to the conventional analogue methods of television-signal timing-correction are outlined in which the signal is stored and time-shifted in digital form. In such an alternative system, the timing information is carried by clock signals, and methods of deriving these clock signals both for writing into, and reading from the stores are discussed.

An experimental digital timing corrector for a video tape machine, controlled by a pilot-tone added to the input signal, has been built and its performance is described; this might be summarised as effecting the complete removal of timing errors at the cost of introducing some chrominance noise.

Future developments are envisaged in which the digital storage may be organised to provide drop-out compensation. In addition the possibility is outline of using digital timing correction in a television-signal synchroniser.

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1. Introduction

The timing stability of television signals, although possibly very high at the source, can be subsequently degraded as the signals pass along the transmission chain. In particular, video tape recording processes tend to introduce considerable timing instabilities because practicable tape-transport systems are incapable of the overall required speed constancy. Video tape recorders of broadcast quality are invariably provided with timing correctors which operate upon the replayed analogue signals and which frequently account for a substantial part of the purchase price of the complete machines.

The effectiveness of timing correction depends entirely upon the ability of a timing signal to convey information concerning timing errors to the corrector. Timing information in the standard PAL colour signal is provided by each synchronising pulse and colour burst and, as these occur only once per line, variations of timing occuring during a line (velocity errors) cannot, in general, be fully corrected although interpolation may be used to optimise performance. If correction of such errors is required, continuous timing signals such as a pilot-tone recorded with the video signal, must be provided.

The development of digital coding of television signals, together with recent advances in solid state digital storage technology, suggest an alternative to conventional analogue methods of timing correction. If a signal with erratic timing can be sampled sufficiently frequently at times determined by 'timing marks' carried by the signal itself, and these samples converted into digital form and written into a shift-register, then, provided that the timing marks in the original signal (say before recording) were strictly regular, the signal may be 'read' from the shift-register at a uniform rate and the timing errors, in principle, eliminated.

A simplified block diagram of a timing corrector of this type, suitable for use with a video recorder, is shown in Fig. 1.

Pilot tone from the generator is added to the video signal before recording and provides the timing marks discussed above. On replay, the video tape recorder mechanism having been synchronised to the local synchronising pulses, the pilot-tone is separated from the replayed video signal and, together with the separated synchronising pulses, is used to generate a train of clock pulses which thus follow the timing variations of the replayed signal.

These clock pulses control the sampling times of the analogue-to-digital converter and 'write' the values of the samples in digital form into the store.

The sample values are 'read' from the store by clock-pulses obtained from second generator controlled by the local synchronizing pulses. The video signal is then reconstituted in analogue form by the digital-to-analogue converter.

A similar result could be brought about, with greater instrumental difficulty by sampling the erratic signal at constant rate, storing it in digital form, and then reading it out with clock-pulses having timing errors equal and opposite to those of the input signal. For simplicity however, only the method in which the writing clock pulses are irregular will be discussed further here.

2. Accuracy of timing extraction

The error to which timing information is subject (when extracted from a signal serving as a timing mark) is inversely proportional to the slope of the timing signal and directly proportional to the noise-level. If timing information is determined from several nominally identical timing-edges, the well known signal-to-noise advantage of 3 dB, due to the coherence of the signal is obtained each time the number of timing-edges used in the determination is doubled.
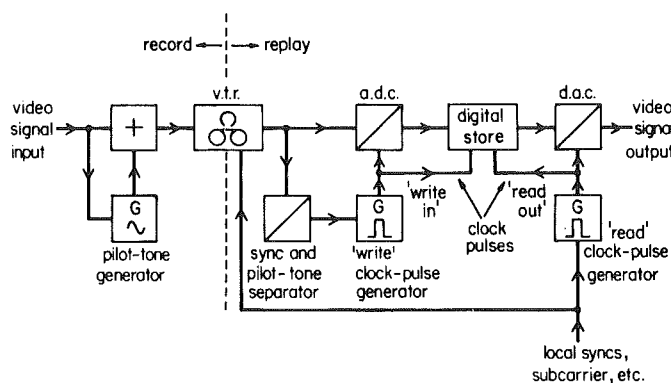

Fig. 1 - Simplified diagram of timing corrector

For a System I colour television signal,[1] the errors in the timing information extracted with a signal-to-noise ratio of 40 dB are as follows:

Extraction from one synchron- ising pulse edge:	41 ns peak-to-peak
Extraction from one zero-crossing of the colour burst:	11·7 ns peak-to-peak
Extraction from 10 successive zero crossings of the colour burst:	3·7 ns peak-to-peak

The impairment caused by timing perturbations of a 625/50 PAL television signal has been measured subjectively with the object of specifying the timing stability requirements of the signal. These results are to be published separately,[2] but may be stated briefly as follows. Periodic or random timing perturbations, of between ¾ ns and 1¼ ns (say 1 ns) are just perceptible by 50% of observers. It was also found during the tests that the visibility of the impairments produced by the periodic perturbations was substantially independent of perturbation frequency over the audio band up to a few kHz, thereby effectively covering the spectrum of timing errors produced by video tape recorders. This value of about 1 ns p-p represents a situation very close to the ideal and, in a practical world, must be regarded as a target specification since no current video tape recorder has a comparable performance. For example, a typical high-quality broadcast video tape recorder, using a conventional timing correction controlled by the line synchronising pulses and colour bursts, is found to deliver signals with perturbations of about 6 ns p-p; it is worth noting that in achieving this figure the corrector is not only affected by random fluctuation noise, but also by moire interference, etc.

If a 1 V peak-to-peak television signal is made non-standard by the addition of a pilot-tone at a level of, say, 100 mV peak-to-peak and a frequency of, say, 5½ MHz, the accuracy of timing extraction from one pilot-tone zero crossing in the presence of noise with an r.m.s. level 40 dB below that of the video signal is 28·3 ns peak-to-peak in the full 5½ MHz bandwidth. However, by the use of a filter, the pilot-channel bandwidth may be reduced and the continuity of the pilot-tone thereby exploited to use many cycles for each zero-crossing determination, and the errors in timing information reduced accordingly. This process must not, of course, be carried too far since too narrow a bandwidth in the pilot-tone channel will suppress information related to rapidly varying timing errors.

3. Generation of clock-control frequencies

To control sampling by the analogue-to-digital converter shown in Fig. 1 and subsequently to write the digitally-coded samples into the store, a set of clock pulses is required. The recurrence frequency of these pulses must be sufficiently high to permit unambiguous sampling of the input video signal, that is 11 MHz or more for System I, and they must contain timing errors which correspond to the timing errors of the input-signal.

Perhaps the simplest solution technically is to employ a pilot-tone of between 5½ and 6½ MHz, accompanying the input video signal; the clock-pulse frequency can then be derived by doubling the pilot-tone frequency. This simple system has the advantage of providing information concerning errors occuring during the active television line and was adopted in the experimental digital timing corrector.

In an alternative arrangement the colour bursts may be used to synchronise an oscillation whose frequency is subsequently tripled to derive the clock-pulse frequency. This latter method has the considerable advantage that it requires no addition to the standard PAL signal. It does not, however, provide continuous correction of error occuring during each line, and further, cannot be used in the simple form just described for reasons to be given below.

4. Cycle-picking

In order to provide successful timing-correction by the digital means under consideration, not only must the timing of the clock signals be sufficiently precise, each pulse must also unambiguously correspond to a certain element in the input signal. Lack of correspondence may result in the input signal (in digital form) suffering timing errors, at the output of the store, of one or more clock-pulse intervals.

If the extraction of the control frequency and hence the clock-pulse signals from the input signal were continuous, grouping of the clock-pulses so as to drive the store correctly could be accomplished by the use of counters. Since, however, the input signal may have discontinuities caused, say, by 'mon-sync. switches', recorder head-switching, dropouts etc., the group of clock-pulses used to fill the digital store must be chosen line-by-line. This process is accomplished by using timing information from the input line-synchronising pulses to 'pick a cycle' of the control frequency at the beginning of each television line and thus select the first of the clock-pulses in a group. It is to be noted that, although the timing inaccuracy of the synchronizing pulse renders it inadequate to serve a means for deriving clock-pulses, it may be entirely suitable for the less stringent requirement of picking out a particular cycle of a separate clock-control signal.
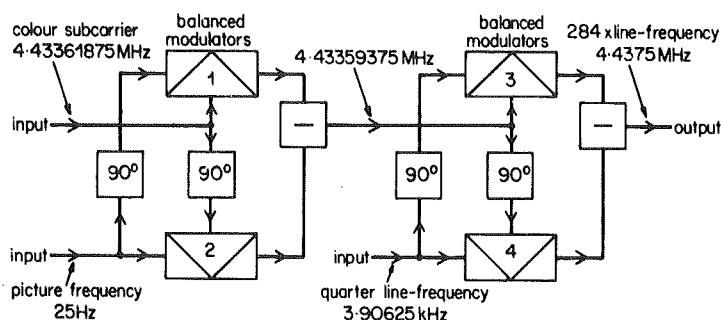
Fig. 2 - Generation of line-locked control frequency from subcarrier

The cycle-picking process is most straight forwardly achieved when the clock-control frequency is provided by a pilot-tone, the frequency of which is an integral multiple of the line-frequency. Provided that the mean timing of the recovered synchronising pulse is suitably adjusted, by automatic means if necessary, cycle-picking can be correctly performed so long as the peak-to-peak timing error of the pulse lies within one period of the pilot-tone frequency.

If the colour subcarrier frequency is used for clock-pulse frequency control, as suggested at the end of section 3, the problems of cycle-picking become more difficult because of the complicated relationship between the PAL subcarrier and line-frequencies. If, in these circumstances, the aforementioned method is used to pick a cycle, it is essential that the peak-to-peak error in the timing of the synchronising pulses be confined within one quarter of the subcarrier period, with the consequent requirement for a 6 dB lower noise level.

However, an alternative arrangement is possible in which the clock-control frequency may be derived from the colour subcarrier, without the necessity to confine sync-edge jitter within such close limits. The frequency of PAL subcarrier is 283¾ x (line-frequency) + (picture frequency). By subtracting picture-frequency (25 Hz) from subcarrier frequency and then adding ¼ x (line-frequency), the integer multiple, 284 x line-frequency may be obtained. This process may be performed by means of a two-stage arrangement of balanced-modulators as shown in Fig. 2. In this arrangement, frequencies may be added or subtracted and the phase-shifts of the inputs are transferred to the output. If the subcarrier input is derived from a television signal with timing errors,

the subcarrier phase-errors will be transferred to the output and the output timing errors will be within 0·1% of those at the input, as the frequency-shifts involved are small.

The line-related frequency, so derived, may be used for clock-pulse frequency control as if it had been a pilot-tone although, as pointed out earlier, if the subcarrier from which it is produced is obtained by reference to the colour bursts, continuous correction of errors occurring during the television line will not be obtained; for relatively low perturbation frequencies, some correction may be obtained by interpolating between the information derived from several colour bursts.

5. Experimental equipment

An experimental digital timing corrector for a video tape recorder has been built in which the writing clock-pulses are controlled by a pilot-tone carried by the signal. A block diagram of this timing corrector is given in Fig. 3.

Timing information is extracted from the pilot-tone by means of a positive-going zero-crossing detector, which discriminates against amplitude modulation of the pilot-tone. The leading edges of the line synchronising pulses, suitably delayed so as to occur, on average, midway between two positive-going pilot-tone zero-crossings, are used to trigger No.1 Bistable which in turn closes the Cycle-Picking Switch. Pilot-tone zero-crossings are thus switched to the Frequency-doubler which forms clock pulses at twice the pilot-tone frequency, and these clock-pulses are counted by the Clock-Pulse Grouping Counter which resets No. 2 Bistable and re-opens the Cycle Picking-Switch as soon as the proper number of clock pulses to make a group have been received.
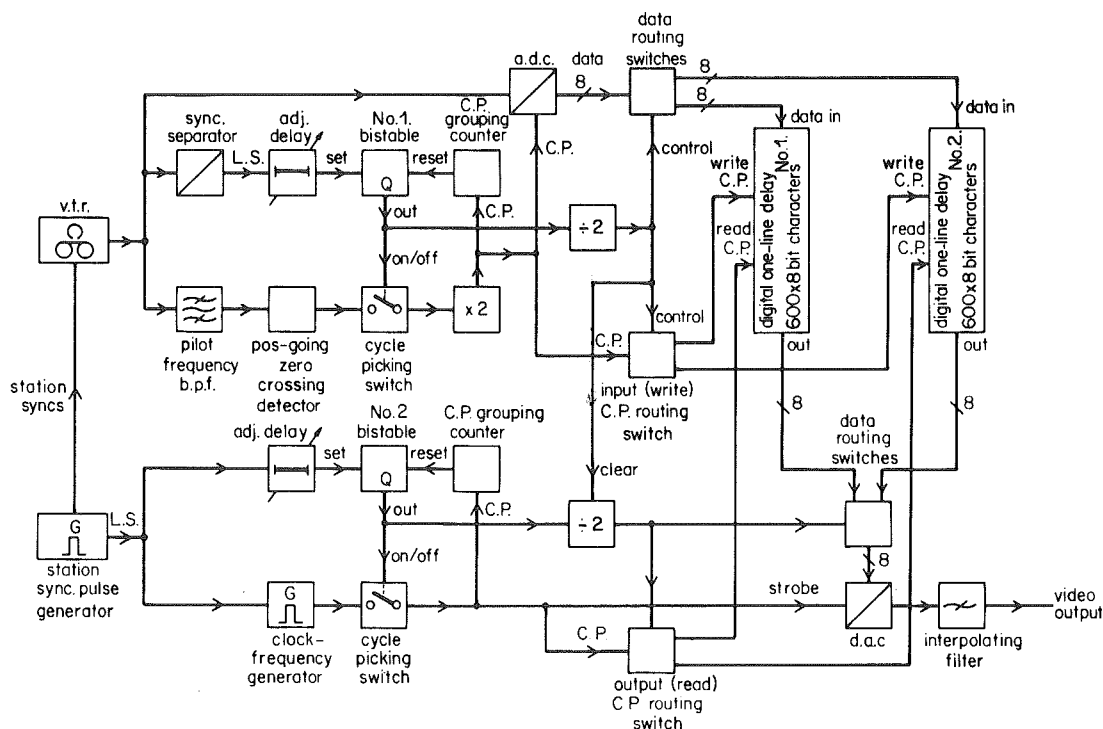

Fig. 3 - Block diagram of complete pilot-tone controlled corrector

Six hundred clock-pulses per group were used in the experimental timing corrector; this corresponds to the number of picture-element samples which could be stored in the digital line-stores employed. At a clock rate of 11 MHz (close to the upper frequency limit of the shift register), this allowed 54·5 μs of storage, rather less than a complete television line including the colour burst.

The grouped clock-pulses control the operation of the Analogue-to-Digital Converter and are routed, as writing clock-pulses, in alternate groups to two Digital One-Line Stores formed from shift registers by means of the Input Clock-Pulse Routing Switch. Control for this switch is obtained by dividing by two the output frequency of No. 1 Bistable. The digital video signal in parallel form from the Analogue-to-Digital Converter is also routed by '8-bit wide' Data-Routing Switches to the input of the appropriate line-store.

The groups of clock-pulses for reading are derived from the station synchronising pulses by methods identical in principle to those adopted for generating the writing clock-pulses. A frequency of 5·5 MHz is first generated by multiplying the local line-synchronising frequency by 704. Timing information from the local line-synchronising pulses is then used to pick a cycle of this clock signal so as start the group, the end of the group being found by counting, as before. Switching of the output clock-pulses to the two shift registers, control of the digital-to-analogue converter, and routing of the store output to the digital-to-analogue converter is accomplished in exactly the same way as for the writing process. It should be noted that a connection is necessary from the write-circuit frequency-divider to the corresponding frequency divider in the read circuits to ensure that reading and writing are not attempted simultaneously in a shift register.

It was pointed out in Section 4, that with a continuous feed of clock-pulses at an exact multiple of line-frequency clock grouping could be accomplished by counting, without recourse to line-by-line cycle-picking. The cycle-picking method was adopted for the reading clock-pulses in the experimental timing corrector simply to save time and money by duplicating an existing arrangement.

6. Experimental results

The experimental timing corrector described above was used to correct the timing of the uncorrected output of a VR 2000 quadruplex video tape recorder. Direct comparison was made with the conventionally corrected output from the Amtec, Colortec and velocity-compensator chain with which the machine is normally used.

Two values of bandwidth of the pilot-tone channel filter were provided (70 kHz and 200 kHz) and the tests were carried out using 100% saturated colour bars, which were found to provide the most critical pictures. Possible patterning effects in the output picture, due to the presence of pilot-tone signal, were eliminated by adjusting the phasing of the a.d.c. clock-pulses to sample at the times of pilot-tone zero-crossings

6.1. Performance with wide-band filter

Using the pilot-tone channel filter with a passband of 200 kHz, the random disturbances of the timing information due to noise (affecting the apparent times of zero-crossings) resulted in a chrominance noise visibility, in the picture, about half a subjective grade worse than that obtained with the normal machine output, using Amtec, Colortec, etc.

Using this filter, the digital timing corrector was able to deal successfully with quite severe maladjustment of the tip-penetration and guide-height controls of the video tape machine.

6.2. Performance with narrow-band filter

Using the pilot-tone channel filter with the narrower passband of 70 kHz the chrominance noise appeared to be similar to that seen using the normal machine output.

For values of maladjustment of recorder tip-penetration deliberately chosen to cause head-switching error with a time-shift corresponding to an odd multiple of half the pilot-tone period, the digital corrector failed to operate correctly on the line immediately following a headswitch, owing to the limited response rate of the filter.

In an operational corrector, quick response at the beginning of the line and low chrominance noise in the picture could be obtained simultaneously be narrowing the filter bandwidth just after the start of the television line. Furthermore, in a helical-scan video tape recorder head-switching of this nature does not occur, and it is likely that very narrow band filters could be used, with consequent improvement in signal-to-noise ratio.

7. Discussion

Current developments in digital storage technology offer economic digital methods for the timing correction of television signals which are comparable in performance with the best conventional analogue method.

Correctors envisaged at present differ mainly in the method of deriving their input clock-pulses. For correctors intended only for monochrome television signals, the clock-pulses could be derived from line synchronising pulses. For PAL colour applications using standard recorded signals, a satisfactory performance appears possible using timing information derived from the line synchronising pulses and the colour bursts. When it is not necessary to adhere rigidly to the standard form of recorded signal, a further improvement in performance could be obtained by use of a pilot-tone added to the input signal. A versatile corrector could be designed to operate in any of the above ways as required. A corrector for a video tape machine could readily be provided with extra

storage to permit drop-out compensation. Further, a wide-range timing corrector would cost little more than a corrector with a range of only a few microseconds. Extension of the storage capacity to permit the correction range to be increased to a whole line would, if required, permit a digital timing corrector to function as a line-store synchronizer.

8. Conclusions

The application of digital techniqeus to the problems of television signal timing-correction has been studied, with particular reference to the methods by which timing information is derived and used to provide suitable clock-pulses.

Methods of clock-pulse control appropriate for monochrome and System I PAL colour signals have been devised which promise satisfactory performances. A further mode of operation using a pilot-tone is envisaged for signals not restricted by current standardization, by means of which a further improvement in performance may be obtained.

Digital timing correction is expected to show a considerable cost-saving over equivalent analogue methods, an advantage that will become even greater as digital storage techniques improve. Further developments of the digital methods to deal with drop-out compensation for video tape and to provide line store synchronizers are also expected.

9. References

1. Specification of television standards for 625-line System transmissions ITA and BBC 1971.

2. BBC Research Department report in the course of preparation.